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Potential urban distribution of *Phlebotomus mascittii* Grassi and *Phlebotomus neglectus* Tonn. (Diptera: Psychodidae) in 2021–50 in Budapest, Hungary

Ákos Bede-Fazekas[1-2] & Attila Trájer[3-4]

[1]*Faculty of Landscape Architecture, Corvinus University of Budapest, Budapest;* [2]*MTA Centre for Ecology, Institute of Ecology and Botany, Vácrátót;* [3]*Department of Limnology, University of Pannonia, Veszprém;* [4]*MTA-PE Limnoecology Research Group of the Hungarian Academy of Sciences, Veszprém, Hungary*

ABSTRACT

Background & objectives: In the Carpathian Basin, the most northern populations of *Phlebotomus* (sandfly) species, including the two studied species (*Phlebotomus mascittii* and *Phlebotomus neglectus*), are reported from central Hungary. The most important limiting factor of the distribution of *Phlebotomus* species in the region is the annual minimum temperature which may be positively affected by the urban heat island and the climate change in the future. The main objective of the study is to prove and predict the overwintering possibility of *Phlebotomus* species in urban environment.

Methods: Based on the latest reports of occurrence of sandfly species, climate envelope model was built for the period 1961–90 and 2025–50 to project the potential urban distribution of the species. The climatic data were obtained from RegCM regional climate model and MODIS satellite images.

Results: The recent occurrence of the species in central Hungary indicates that *Phlebotomus* species can overwinter in non-heated shelters in built environment.

Interpretation & conclusion: Jointly heat island and the increase of minimum temperature in winter due to climate change seem to be able to provide suitable environment for the studied species in urban areas to a great extent.

Key words Climate change; leishmaniasis; sandfly; UHI; urban heat island

INTRODUCTION

The *Phlebotomus* (sandfly) vectors of *Leishmania infantum* are endemic primarily in the Mediterranean areas in Europe, but since 1931, *Phlebotomus* species are reported from southern Hungary[1-2] and in the 1960s the Medical Services, observed the presence of *Phlebotomus perfiliewi* in Budapest[1]. Recently, species *Phlebotomus (La.) neglectus*, *Phlebotomus (La.) perfiliewi*, *Phlebotomus (Tr.) mascittii* and *Phlebotomus papatasi* have been recognized as the members of the Hungarian fauna of genus *Phlebotomus* (Diptera: Psychodidae)[2]. These populations live in those areas of Hungary having mild winters: zonally in the southern counties, extrazonally in the Balaton uplands and in the agglomeration of the capital of Hungary. It is conceivable that the presence of *Phlebotomus mascittii* in the Balaton uplands may be the consequence of the climate-moderating effect of the largest lake of central Europe and similarly, the historical presence of *P. perfiliewi* in Budapest and the contemporary observations of *P. mascittii* and *P. neglectus* in the agglomeration can be explained by the (winter) urban heat island (UHI) effect of the capital, since this is the most northern confirmed occurrence of the sandfly species in Hungary and the adjacent countries in the Carpathian Basin[2].

It is known that *Phlebotomus* species can easily adapt to the urban environments[3], for example, *P. perniciosus* one of the most important vector of *Leishmania* parasites in Europe, is able to colonized in rural, peri-urban and urban areas[4–7]. The life-cycle of *L. infantum* is distinctly peridomestic. In Portugal, it has been found that leishmaniasis cases are associated with dogs and urban areas[8]. The main objective of this paper is to predict the potential future distribution of *P. mascittii* and *P. neglectus* in urban environment based on macroclimatic and UHI data and to examine whether recent occurrence of the species in central Hungary indicates that *Phlebotomus* species will be able to overwinter in nonheated shelters in and near Budapest.

MATERIAL & METHODS

The approach of the study

According to the literature detailed above, not only natural refuges can serve as suitable habitats for sandflies but buildings in the urban context as well. We aimed to run climate envelope model (CEM) to study the potential distribution of *P. mascittii* and *P. neglectus* in the period of 2021–50 in Pest County, central Hungary. The model is based on the observation of these two sandfly species during 2006–09 in Törökbálint, suburb of Budapest (47.436N, 18.916E)[2], the UHI of Budapest and its agglomeration calculated on the basis of satellite images, and on the predictions for the reference (1961–90) and the future (2021–50) period of RegCM3 regional climate model.

Data sources

The ground temperature data of Budapest and its surroundings were obtained from moderate resolution imaging spectroradiometer sensor (MODIS) of the Aqua satellite of NASA[9]. The satellite has quasi-polar orbit and make images between 2 and 3 UTC and between 12 and13 UTC around the selected region[10]. Since, the colder temperatures had importance in this research, the images taken at night were obtained. In all, 2893 points from the grid of 4900 points were selected from the rectangular region between latitude 47.225 N and 47.660 N, and longitude 18.767 E and 19.454 E of WGS-84 coordinates. Between 1 January 2003 and 31 December 2008, 643 images were taken which had < 20% data absence[11]. Only those images were studied that were taken in a specific climatic situation, *i.e.* when the rural mean temperature was lower than –10°C (n = 29). For detailed information about distinction of rural and ruban data see publications of Lelovics[11-12]. The seven images which were selected among them can be seen in Fig. 1 with the rural mean temperature and the difference of urban and rural temperatures. The selected images were taken on dates 14 February 2003, 13 January 2003, 12 February 2003, 7 February 2006, 6 January 2004, 2 March 2005, and 24 February 2003 with rural mean temperatures of –19.01, 18.79, –16.49, –14.70, –13.29, –12.52, and –10.44°C, respectively. The mean difference of the rural and urban temperature was 3.28°C.

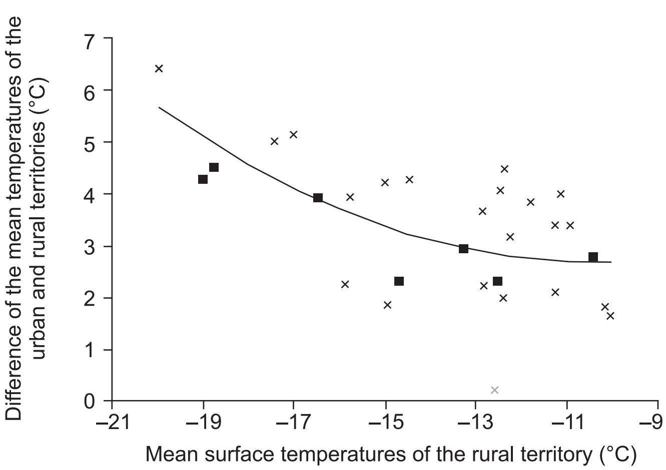

Fig. 1: The difference of the mean temperatures of the urban and rural territories with a second order regression line. Only the days with < 20% data absence and with rural mean temperature lower than –10°C are displayed. The selected seven days are marked with square symbol.

The effect of climate change was derived from the downscaled RegCM3 regional climate model[13-14] with the aforementioned domain. The model was based on the scenario A1B of the Special Report on Emission Scenarios (SRES) of Intergovernmental Panel on Climate Change (IPCC)[15]. The most important limiting factor of the distribution of *Phlebotomus* species in the region is the annual minimum temperature[16], therefore, the horizontal average of the minimum of daily minimum ground temperatures in January was used from the reference period 1961–90 and the prediction period 2025–50. The horizontal resolution of the grid was 10 km, and 48 points were found between latitude 47.2208 N and 47.7958 N and longitude 18.6073 E and 19.6740 E (the domain of the 4900 satellite data).

Software and statistics

R statistic analyzer and Microsoft Excel 2010 were used as data preprocessors. GIS modeling was achieved by ESRI ArcGIS 10 software, and the output layouts were edited by Adobe Photoshop.

Modeling methods

It was supposed that both the impact of urban heat island and future climate change encourage sandfly species to overwinter in open space. *Eq. 1* (Reference period) and *Eq. 2* (Prediction period) show the calculations made to study whether Budapest and its surroundings provide suitable environment in climatic terms for the sandfly species.

$$f = \begin{cases} \textit{climatically suitable, if } T_{\min,\,jan}^{1961\text{–}1990} > T_{\min,\,jan}^{1961\text{–}1990,\ observed} \\ \neg(\textit{climatically suitable}), \textit{ if } T_{\min,\,jan}^{1961\text{–}1990} \leq T_{\min,\,jan}^{1961\text{–}1990,\ observed} \end{cases} \qquad (Eq\ ...1)$$

$$f = \begin{cases} \textit{climatically suitable, if } T_{\min,\,jan}^{2025\text{–}2050} > T_{\min,\,jan}^{1961\text{–}1990,\ observed} \\ \neg(\textit{climatically suitable}), \textit{ if } T_{\min,\,jan}^{2025\text{–}2050} \leq T_{\min,\,jan}^{1961\text{–}1990,\ observed} \end{cases} \qquad (Eq\ ...2)$$

The ground temperature of a certain location was calculated based on the ground temperature data of RegCM model and the temperature difference caused by urban heat island (*Eq. 3*).

$$Tmin,\, jan = mean\left(T_{\min,\,jan}^{ground}\right) + mean\,(\Delta T_{UHI}) \qquad (Eq\ ...3)$$

The effect of urban heat island was calculated by a script written in R for all the 4900 studied points. Previous studies showed that both second order polynomial regression and linear regression with major axis method are highly unstable for calculating the base temperature dependence of the volume of the urban heat island. Therefore, simple averaging was done based on the seven selected images. The maximum and the minimum of the urban heat island effect were +4.51°C, and +2.30°C, respectively.

After data exportation from Microsoft Excel 2010, the result was displayed by ESRI ArcGIS 10 software. The temperature grids were interpolated by inverse distance weighted (IDW) method with power 2 and 12 neighbouring points. The isotherms were displayed by Contour method of Spatial Analyst extension and projected onto one map. Digital NUTS3 polygon borders[17] and the river Danube were displayed to help orientation.

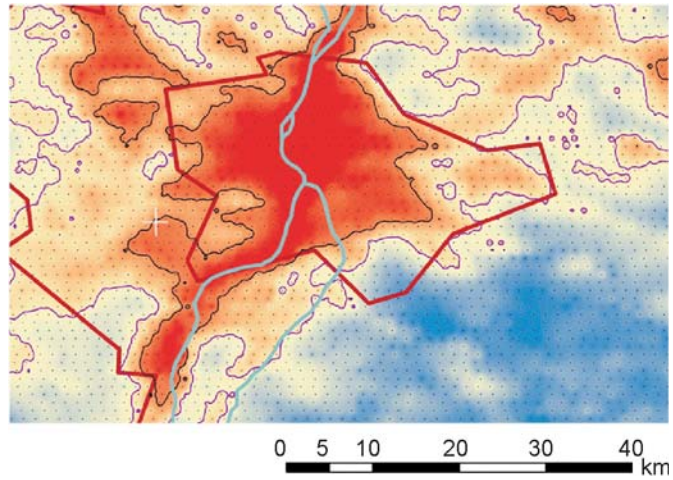

Fig. 2: The average effect of urban heat island (Blue-red), observation of Farkas *et al*[2] (White cross), and the potential urban distribution of *P. mascittii* and *P. neglectus* in the reference period (Black contour) and in the period of 2025–50 (Purple contour) in the simplified base map of Pest county, Hungary.

RESULTS

In the location of the recent observation of the two studied species (Törökbálint, 47.436 N, 18.916 E)[2], the warming effect of urban heat island was found to be 2.69°C. According to the RegCM climate model the minimum ground temperature of January is –15.91°C in the reference period and –13.96°C in the prediction period. Since, the studied sandflies can tolerate – 4°C[18], the sheltering effect of the built environment was about 12°C. Fig. 2. shows the resulted border of the potential urban distribution of the studied species in case of both the periods *i.e.*, 1961–90 and 2025–50. Figure 2 also displays the data points of the satellite image and the calculated effect of the urban heat island with a blue-red colour ramp. The observation of the two sandfly species, which gives the base of this research, was marked with white cross. In the reference period, 57.81% of Budapest was modeled to be climatically suitable for the species, while in 2025–50, 89.37% of the town may become suitable. Figure 3 shows statistics and frequency distribution of the minimum ground temperature of January found within the modeled urban distributions of the species in the reference period and the projection period. In total, 915 points (348 points—38.03% in Budapest) were modeled to be suitable in the reference period and 2386 point (538 point—22.55% in Budapest) in the projection period. The enlargement of the potentially suitable territories is 161% (between 1961–90 and 2025–50).

DISCUSSION

The urban heat island effect is the principal driver of warming at urban scale[19]. Some researchers[20] consider the problem of the UHI that may become as important issue as, or even more important issue than, that of global warming since the rate of urban warming may be greater than the rate of global warming. Note, that synergic effects can also arise.

Due to the UHI, the studied sandfly species have isolated occurrence in the urban area. Our findings indicate that this fragmented distribution may become the source of rapid future expansion of the sandfly species and consequently leishmaniasis may become serious problem in the highly populated urban area. In agreement with Rosenzweig*et al*[21], who stated that UHI-related hazard potential is likely to increase in a warmer climate, we should highlight that climate change can increase the risk of leishmaniasis in Budapest and in some other highly populated areas as well. According to the VBORNET database[22] in the case of the insulated distribution of *P. ariasi* in Paris the situation is very similar to the studied two species in Hungary, as the French capital is also the northern most of region occurrence of the sandfly species.

The magnitude of climate moderating (sheltering) effect of the built environment (about 12°C) was more than it was expected. In case the known cold tolerance limit of the *Phlebotomus* larvae is valid our study indicates that *P. mascittii* and *P. neglectus* can tolerate

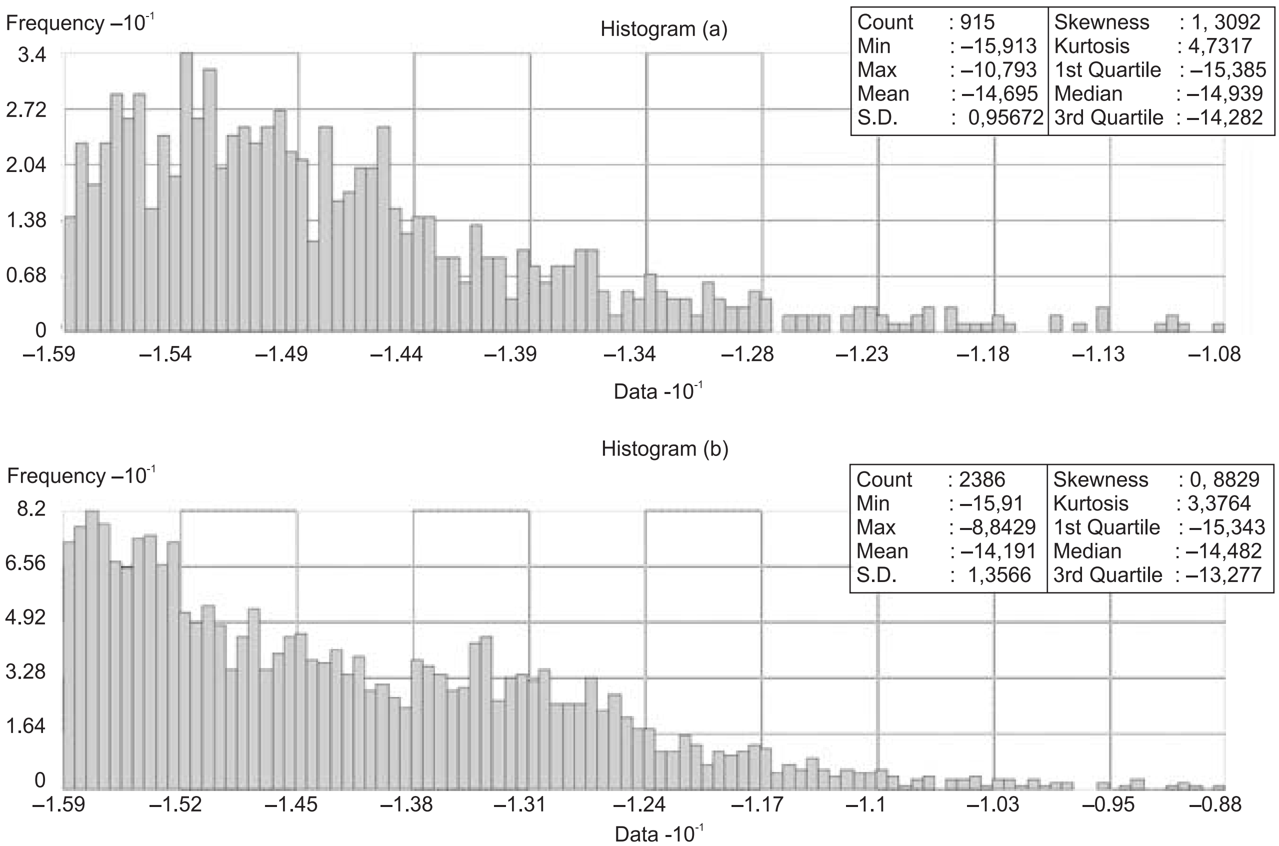

Fig. 3: Frequency distribution and statistics of the minimum ground temperature of January (Scale: 10°C) within the modeled urban distribution of the studied species in the reference period from 1961–90 (Histogram a); and the period from 2025–50 (Histogram b).

severe winters by utilizing the human built environments more than was previously thought. The authors suppose that the species could overwinter inside sheds, garages, cellars and other unheated ancillary buildings. Note that our model was based on the field study of Farkas *et al*[2] who found the *Phlebotomus* species in a territory that had suburban characteristics within 2 km radius, which is the known dispersal limit of the species[23]. In that place there were no haycocks, livestock, piles of manure, gopher holes and other non-anthropogenic shelters which could facilitate the overwintering of sandfly larvae.

Due to the predictions of Trájer *et al*[16, 24] some other *Phlebotomus* species (most of all *P. perfiliewi, P. tobbi* and *P. ariasi*) seem to be able to potentially survive the climate of Budapest, in spite of the fact that some of them are less hardy to cold conditions. Our study proves the findings of Trájer *et al*[16] since it seems to be unambiguous that the known cold tolerance of the larvae has only indirect impact on the potential distribution.

The recently developed UHI simulation approaches are still not able to cover all the phenomena that simultaneously contribute to the formation of UHI[25]. Though, our model assumes constant UHI similarly to some other researches[26], it should be mentioned that the UHI of Budapest may increase in the future. Climate change has the potential to alter the intensity, temporal pattern, and spatial extent of the UHI in metropolitan regions—Particular meteorological conditions, including high temperature, low cloud cover, and low average wind speed, tend to intensify the heat island effect[21]. We should also note that if the urban heat island effect is playing a role not only in the present day spatial temperature difference, but the rate of increase in urban temperatures overtime, then projections for climate change may underestimate the true extent of warming experienced in urban areas[18, 27-28]. Therefore, our model has the chance of underestimating the expansion of the future potential urban distribution of the studied species.

It is known that the magnitude of UHI depends on the city size and the number of inhabitants[29]. Although, the population of Budapest has been decreased for some decades, the city-suburban complex has not been shrinking. Moreover, the research of Emmanuel and Krüger[30] shows that the UHI itself does not go away, even in shrinking cities. Even though the population of Budapest has not shown increasing trend, the energy consumption—

and very likely the heat pollution of its —inhabitants has been mounted up in the last decades[31], and may increase in the future as well.

CONCLUSION

We have presented that the recently observed northern most occurrence of *P. mascittii* and *P. neglectus* in the agglomeration of the Hungarian capital, Budapest would be the consequent of the UHI of the city. It is also very likely that due to the effect of climate change the recent insulated occurrence of this sandfly species will expand towards the rural areas. Our findings indicate that the present-day relatively small, extrazonal urban populations of the sandfly species will become the source of their more rapid expansion than we might expect on the basis of the recent zonal distribution of this species. It was found that the studied species can tolerate harder winters by utilizing the human built environments more than was previously thought. Our results show that further studies should pay particular attention to the UHI and also the role of the long-distance trade, which has the potential to transport the vectors from the zonal distribution to the northern cities, in the climate envelope modeling of sandflies and other important vector species.

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Correspondence to: Ákos Bede-Fazekas, H-1118 Budapest, Villányi út 29–43, Hungary.
E-mail: bfakos@gmail.com

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